

# The role of mosses in ecosystem succession and function in Alaska's boreal forest<sup>1</sup>

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**Abstract:** Shifts in moss communities may affect the resilience of boreal ecosystems to a changing climate because of the role of moss species in regulating soil climate and biogeochemical cycling. Here, we use long-term data analysis and literature synthesis to examine the role of moss in ecosystem succession, productivity, and decomposition. In Alaskan forests, moss abundance showed a unimodal distribution with time since fire, peaking 30–70 years post-fire. We found no evidence of mosses compensating for low vascular productivity in low-fertility sites at large scales, although a trade-off between moss and vascular productivity was evident in intermediate-productivity sites. Mosses contributed 48% and 20% of wetland and upland productivity, respectively, but produced tissue that decomposed more slowly than both nonwoody and woody vascular tissues. Increasing fire frequency in Alaska is likely to favor feather moss proliferation and decrease *Sphagnum* abundance, which will reduce soil moisture retention and decrease peat accumulation, likely leading to deeper burning during wildfire and accelerated permafrost thaw. The roles of moss traits in regulating key aspects of boreal performance (ecosystem N supply, C sequestration, permafrost stability, and fire severity) represent critical areas for understanding the resilience of Alaska's boreal forest region under changing climate and disturbance regimes.

**Résumé :** Des changements dans les communautés de mousses peuvent altérer la résistance des écosystèmes boréaux aux changements climatiques à cause du rôle des espèces de mousses dans la régulation du pédoclimat et le recyclage biogéochimique. Dans cette étude, nous avons eu recours à l'analyse de données à long terme et à une synthèse de la littérature pour étudier le rôle des mousses dans la succession, la productivité et la décomposition dans les écosystèmes. Dans les forêts de l'Alaska, l'abondance des mousses a une distribution unimodale dans le temps avec un maximum qui survient 30–70 ans après un feu. Nous n'avons pas trouvé d'indice à grande échelle démontrant que les mousses compensent la faible productivité des plantes vasculaires dans les stations à faible productivité. Par contre, un compromis entre la productivité des mousses et celle des plantes vasculaires était évident dans les stations à productivité intermédiaire. Les mousses étaient responsables de respectivement 48 % et 20 % de la productivité des zones humides et sèches, mais elles produisaient des tissus qui se décomposent plus lentement que les tissus vasculaires photosynthétiques et ligneux. L'augmentation de la fréquence des feux en Alaska va probablement favoriser la prolifération des mousses hypnacées et diminuer l'abondance des *Sphagnum*. Cela va diminuer la rétention de l'humidité dans le sol et réduire l'accumulation de tourbe, ce qui entraînera probablement un brûlage plus en profondeur lors de feux de forêt et la fonte accélérée du pergélisol. Les rôles associés aux caractéristiques des mousses dans la régulation des aspects clés de la performance des écosystèmes boréaux (l'apport de N dans l'écosystème, la séquestration de C, la stabilité du pergélisol et la sévérité du feu) représentent des domaines cruciaux pour comprendre la résilience de la région de la forêt boréale de l'Alaska face aux changements du climat et des régimes de perturbation.

[Traduit par la Rédaction]

## Introduction

Mosses, one of the major groups of bryophytes, are ubiquitous and dominant components of ground-layer vegetation in both upland forests and peatlands across the boreal biome. These plants have received attention in several recent reviews for their importance in regulating soil hydroclimate and nutrient cycling in boreal ecosystems (van Breemen

1995; Turetsky 2003; Nilsson and Wardle 2005). Recent studies affiliated with the Bonanza Creek Long Term Ecological Research (BNZ-LTER) program also have documented relationships between moss composition and ecosystem parameters such as aboveground tree productivity and soil C storage (Hollingsworth et al. 2008) and have suggested that moss abundance plays a critical role in post-fire successional trajectories (Johnstone et al. 2010) and perma-

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frost stability (Jorgenson et al. 2010). Given that interior Alaska is experiencing rapid climate change (Hinzman et al. 2005), many stand- and regional- level models predict shifts in the dominant canopy structure of Alaskan ecosystems. However, to date, changing moss community composition and its influence on boreal ecosystem function in Alaska typically have been overlooked.

Generally, moss biomass on the forest floor tends to be effective in buffering soils from variation in atmospheric climate because of its low thermal conductivity, high porosity, and high water holding capacity (Rydin and McDonald 1985; O'Donnell et al. 2009). In addition to controlling soil climate, mosses regulate C and nutrient cycling in boreal ecosystems by (i) contributing to ecosystem net primary productivity, (ii) contributing to ecosystem N inputs via N-fixing symbioses with cyanobacteria (DeLuca et al. 2002), (iii) effectively sequestering atmospheric N, thereby preventing N uptake by vascular plants (Li and Vitt 1997), (iv) producing recalcitrant litter that resists microbial breakdown (Hobbie et al. 2000; Lang et al. 2009), and (v) regulating plant community structure by inhibiting seedling germination and the success of many boreal tree species (Johnstone et al. 2010).

Because mosses possess unique physiological and ecological traits that influence soil climate, nutrient cycling, and vascular plant germination, changes in moss structure and function are important for predicting future landscape patterns and processes in a changing climate across the boreal region. While the BNZ-LTER program has long recognized the linkages between mosses, peat accumulation, and permafrost dynamics, and the importance of these linkages for boreal forest nutrient cycling (Van Cleve et al. 1991), studies within the BNZ-LTER program have tended to focus on the controls of vascular plant species on ecosystem functioning and resource supply. For example, many models predicting future landscapes scenarios use dominant overstory type (deciduous versus coniferous) to represent differences in community structure and function. However, by producing biomass, storing water, regulating nutrient cycling, and protecting permafrost, changes in mosses will affect the structure and function of boreal ecosystems in the face of directional climate change and altered disturbance regimes.

Here, we first use long-term BNZ-LTER data to determine whether boreal moss communities show consistent successional trajectories during both primary (post-flooding in floodplains) and secondary (post-fire in forests) succession in interior Alaska. Second, we use literature synthesis to test several common assumptions about the role of mosses in two key aspects of ecosystem function (productivity and decomposition) and to evaluate how mosses contribute to the resilience of northern ecosystems by regulating soil climate, permafrost stability, and fire severity.

## Methods

### Moss succession

In interior Alaska, upland forests and floodplains differ in the mechanisms that initiate succession, with primary succession in floodplain sites triggered by river flooding and secondary succession in upland forests triggered primarily by wildfire. We examined changes in moss abundance and

diversity across BNZ-LTER vegetation monitoring sites, which represent various stages of forest or floodplain succession (Hollingsworth et al. 2010). We analyzed the most recent data (either 2007 or 2008) collected across the LTER floodplain (FP sites) and upland forest sites (UP sites). The upland sites included stands dominated by deciduous shrub and mixed deciduous and coniferous seedlings and saplings that burned in 1984 (UP1s), mature deciduous stands of birch and aspen (UP2s), mature white spruce (*Picea glauca* (Moench) Voss) stands (UP3s), and mature black spruce (*Picea mariana* (Mill.) BSP) stands (UP4s). More details on the floodplain sites can be found in Hollingsworth et al. (2010). To further examine patterns of mosses abundance during post-fire succession, we analyzed data from 25 forest stands across interior Alaska ranging from 0 to 93 years post-fire (Appendix A, Table A1). Of these 25 sites, nine sites were measured repeatedly after fire (eight as part of the BNZ LTER program; Appendix A, Table A1). The remaining 16 sites were measured once after fire (Appendix A, Table A1).

For the majority of sites, moss abundance (percent species cover and percent total moss cover) was quantified in permanent plots ranging from 60 cm<sup>2</sup> to 1 m<sup>2</sup> in area. Within-site replication varied from 4 to 20 plots (Appendix A, Table A1). All data reported here represent within-site means averaged across the plot.

We explored changes in four moss groups that vary in successional dynamics and resource acquisition (light and moisture): (i) colonizer species including *Ceradaton purpureus*, *Pohlia* spp., *Leptobryum* spp., and *Polytrichum* spp., (ii) feather moss species including *Hylocomium splendens*, *Pleurozium schreberi*, and *Ptilium crista-castrensis*, (iii) other true moss species including *Aulacomnium* spp., *Tomenthypnum nitens*, and *Dicranum* spp., and (iv) *Sphagnum* spp. including *Sphagnum fuscum*, *Sphagnum angustifolium*, and *Sphagnum warnstorffii*. We examined differences in total moss abundance as well as the abundance of these moss groups across the upland forest and floodplain successional stages using a one-way ANOVA model and Tukey–Kramer post hoc tests to differentiate among means.

### Net primary productivity

To examine relationships between moss and vascular productivity, we examined 113 published studies of northern ecosystems that reported measurements of moss growth rates. Of these, 38 studies reported moss net primary productivity in grams per square metre per year and 17 quantified both moss and aboveground vascular productivity. We chose the latter subset of sites to test the hypothesis that mosses are equally important as black spruce in contributing to total ecosystem productivity (Oechel and Van Cleve 1986). Notably, all of these studies were from North America. From the 17 studies, we identified 70 spatially and structurally distinct sites where the productivity of each stratum (i.e., moss, understory vascular, and tree overstory) was either directly measured or estimated (Appendix A, Table A2). Sites ranged from the southern edge of the boreal region in Minnesota (47°30'N), across boreal Canada, to the North Slope of the Brooks Range, Alaska (68°38'N), and included 22 boreal and tundra wetlands, 30 upland boreal forest or tundra sites with permafrost, and 12 upland boreal

forest sites without permafrost. Well-drained sites such as forests and permafrost plateaus were considered to be uplands and more poorly drained sites such as marshes, bogs, fens, and permafrost collapse scars were considered to be wetlands. The methods for measurements of moss productivity ranged from high-intensity cranked wire (Clymo 1970), fluorescent staining (Russell 1988), or tagged branch methods (Ruess et al. 2003) to low-intensity estimates such as the multiplication of green moss biomass times a site-specific (e.g., Hobbie and Chapin 1998) or regional-specific (e.g., Shaver et al. 1996) growth ratio. For productivity of the vascular understory in forests or total vascular biomass in tundra, methods generally consisted of destructive harvests and separation of new and old growth via morphological markers (e.g., Schuur et al. 2007). Tree overstory productivity was measured via inventory, allometry, and (or) litter traps (e.g., Mack et al. 2008).

We note that these sites most likely had substantial cover of both moss and vascular species. Obviously missing from these sites are ecosystems where one of the two groups was poorly represented, such as high-productivity stands dominated by hardwoods or conifer species other than black spruce, low-productivity heath tundra or woodlands, and nontreed wetland classes such as open fens or emergent-dominated marshes. Thus, our analyses are constrained to structurally diverse, intermediate-productivity forests and wetlands where mosses and vascular plants both contribute to productivity.

We used general linear models (GLMs) to examine the effects of landscape position (upland and wetland), soil permafrost status, and the landscape position  $\times$  permafrost status interaction on moss, understory vascular, and ecosystem aboveground productivity. All data were  $\ln$  transformed to meet statistical assumptions if necessary. We used a one-way GLM and Bonferroni post hoc tests to examine differences among black spruce means. The nature of relationships between moss and vascular productivity were examined with Pearson product moment correlations. Probabilities were corrected for multiple observations using the Bonferroni method. To determine whether the ratio of moss to black spruce productivity differed systematically across landscape position or permafrost, we employed Pearson  $\chi^2$  tests.

### Litter mass loss

To examine patterns of decomposition among moss groups, we build on the decomposition synthesis of Hobbie et al. (2000). Averaged across species, we predicted that moss biomass decomposes more slowly than vascular non-woody tissue (Hobbie et al. 2000) but more quickly than woody tissues. However, we also hypothesized that *Sphagnum* spp. in section *Acutifolia* (typically hummock-forming species) decompose more slowly than other boreal moss species because of their unique structural traits that influence litter quality (i.e., Turetsky et al. 2008). To test these hypotheses, we examined published studies of northern ecosystems that reported measurements of moss and (or) vascular tissue mass loss. We identified 29 studies that reported mass loss data as a percentage of mass remaining. From these studies, we identified approximately 65 distinct sites in which moss or vascular tissues were decomposed. The data set included study sites in Canada, Alaska, Finland,

Sweden, and eastern European countries. Following Hobbie et al. (2000), we primarily confined our analysis to studies that employed the litter bag technique in situ to quantify 1-year mass loss rates. We relied on mass loss of litter bags placed at or near the soil surface and avoided mass loss data from litter bags placed deeper in peat profiles. Mass loss rates over the first year of field incubation were used to enable comparison across studies.

Mass loss rates are reported as mean percentage of original mass lost, and rates were estimated from figures if necessary. For each mean mass loss value, we recorded plant organ (fine root, root, leaf, moss, etc.), growth form (deciduous, evergreen, herbaceous, and moss), and landscape position (upland and wetland) from site description information. Pristine or drained peatlands, marshes, and lags were recorded as wetlands, while forests, tussock, and tundra sites were recorded as uplands. In total, we compiled 242 mass loss values in wetlands and 95 values in uplands (Appendix A, Table A3).

We used GLMs to examine the effects of landscape position (upland and wetland), plant organ (i.e., leaves, needles, root, moss, etc.), vascular growth form (deciduous, evergreen, and herbaceous), and a landscape position  $\times$  plant organ interaction on mass loss rates. We used Bonferroni tests for post hoc comparison of means. We also categorized moss species into taxonomic groups, including (i) feather moss species, (ii) true moss species, (iii) *Sphagnum* spp. in section *Cuspidata*, (iv) *Sphagnum* section *Acutifolia*, and (v) *Sphagnum* section *Sphagnum*. There are strong correlations in *Sphagnum* between phylogeny and habitat, as species of sections *Acutifolia*, *Cuspidata*, and *Sphagnum* often grow in hummocks, wet carpets and lawns, and midhummocks, respectively (cf. Gunnarsson 2005).

## Results

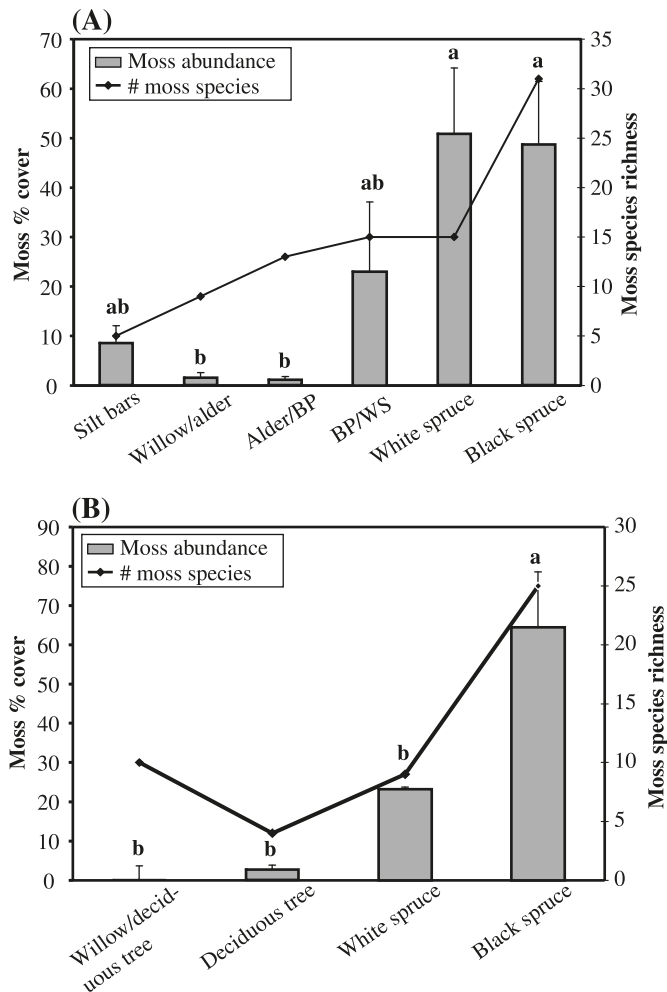
### Moss succession

Moss abundance varied with successional stage in the sites representing primary (floodplains:  $F_{[2,17]} = 5.82$ ,  $p = 0.01$ ) and secondary succession (uplands:  $F_{[2,12]} = 12.69$ ,  $p = 0.01$ ) (Fig. 1). In general, moss abundance and species richness increased through succession. One exception was in the uplands sites, as the willow–deciduous sites had higher species richness than the deciduous sites. Prior to burning in the 1984 Rosie Creek fire, the willow–deciduous sites were characterized by mixed deciduous–white spruce stands. The survival of residual moss species at low abundances post-fire likely contributed to high species richness.

Despite this general pattern of increasing moss abundance and species richness during succession, there were some key differences between primary and secondary succession in patterns of total moss abundance. In both floodplains and uplands, early-successional sites were characterized by low moss cover (less than 10% cover). In the floodplains, large changes in moss abundance occurred in mid-successional stages, while in the uplands, there were large increases in moss abundance later in the successional sequence. Late in succession, mosses were in greater abundance in the uplands (62% cover) than in the floodplains (45% cover). The abundance of colonizer species decreased across the primary successional stages in the floodplains ( $F_{[5,15]} = 4.46$ ,  $p = 0.02$ )



**Fig. 1.** Moss total abundance and species richness across the (A) floodplain, and (B) upland forest successional sequences (means  $\pm$  1 SE).



but showed no pattern in the secondary successional upland forests (Table 1). Feather mosses and other true moss species tended to increase in abundance through both primary ( $F_{[5,15]} = 3.51$ ,  $p = 0.04$ ) and secondary succession ( $F_{[3,12]} = 11.81$ ,  $p < 0.01$ ). In both the floodplain and upland sites, *Sphagnum* mosses only occurred in late-successional black spruce sites (Table 1).

We used a larger data set to analyze patterns of secondary succession in forests with and without surface permafrost. While moss abundance increased fairly linearly with each successional stage across the LTER forest sequence (Fig. 1), this larger data set revealed a more complex picture of moss succession. In permafrost-free sites, total moss abundance followed a unimodal distribution with time since fire, with the highest abundance occurring 30–70 years post-fire (Fig. 2A). In permafrost sites, total moss abundance increased rapidly in the first approximately 20 years post-fire, with no change over the next 50 years. Colonizer species in both permafrost and permafrost-free sites showed a unimodal pattern of abundance, peaking within the first decade post-fire in permafrost-free sites and within approximately

35 years post-fire in permafrost sites (Fig. 2B). However, there was high variability in the establishment of this successional group, as many early-successional sites (particularly permafrost-free sites) had very low abundances of colonizer species. Overall variation in the colonizer species group was primarily driven by *C. purpureus* and to a lesser degree by *Polytrichum* spp., which continued to be present in some permafrost-free sites up to 90 years post-fire. The abundance of “other true mosses” tended to be low in both permafrost and permafrost-free forests but were present in higher abundances in some mid-successional forests with permafrost (Fig. 2C). Finally, feather moss abundance also appeared to correspond to a unimodal distribution in both permafrost and permafrost-free sites, with low abundance in both early- and late-successional sites but high variation in mid-successional sites (Fig. 2D). We found little data on the abundance of this moss group in more mature permafrost stands. *Sphagnum* spp. were found only in permafrost sites in low abundance (less than 5% abundance) and showed no pattern with time post-fire (data not shown).

### Moss and vascular plant productivity

Moss and aboveground understory vascular plant production were higher in wetlands than in uplands ( $F_{[1,63]} = 12.033$ ,  $p = 0.001$  and  $F_{[1,47]} = 3.375$ ,  $p = 0.07$  for moss and understory, respectively), independent of whether permafrost was present or absent (Fig. 3). Aboveground productivity of black spruce also varied between uplands and wetlands but was more sensitive to the presence or absence of permafrost. Black spruce were more productive in permafrost-free uplands ( $F_{[1,40]} = 7.687$ ,  $p = 0.001$ ) than in permafrost-free wetlands ( $p = 0.001$ ) or permafrost uplands ( $p = 0.07$ ). Total site productivity did not differ between landscape position or permafrost status because high black spruce productivity tended to compensate for low moss and understory productivity in uplands, while high moss and understory productivity compensated for low black spruce productivity in wetlands (Figs. 3 and 4).

Across sites, moss productivity averaged  $8.46 \pm 6.78$ ,  $81.44 \pm 20.69$ ,  $50.44 \pm 8.21$ ,  $47.57 \pm 8.16$ , and  $162.17 \pm 25.33$   $\text{g} \cdot \text{m}^{-2} \cdot \text{year}^{-1}$  (mean  $\pm$  1 SE) for communities dominated by early colonizers, other true moss species, feather moss species, a mix of feather moss and *Sphagnum* spp., or *Sphagnum* spp., respectively. Within uplands, feather moss showed little variation in productivity among permafrost and permafrost-free sites, while *Sphagnum* occurred only in permafrost uplands, with an average mixed *Sphagnum*–feather moss productivity of  $56.11 \pm 11.33$   $\text{g} \cdot \text{m}^{-2} \cdot \text{year}^{-1}$ . In wetland sites, however, *Sphagnum* productivity was more than threefold higher than in forests, with average productivity rates of  $162.98 \pm 27.07$   $\text{g} \cdot \text{m}^{-2} \cdot \text{year}^{-1}$  (Appendix A, Table A1). Likewise, the productivity of other true moss species was about threefold higher in wetlands than in uplands, averaging  $17.50 \pm 12.5$  and  $102.75 \pm 20.61$   $\text{g} \cdot \text{m}^{-2} \cdot \text{year}^{-1}$  in permafrost uplands and nonpermafrost wetlands, respectively. We found no productivity data for pioneer species or feather mosses in wetland environments.

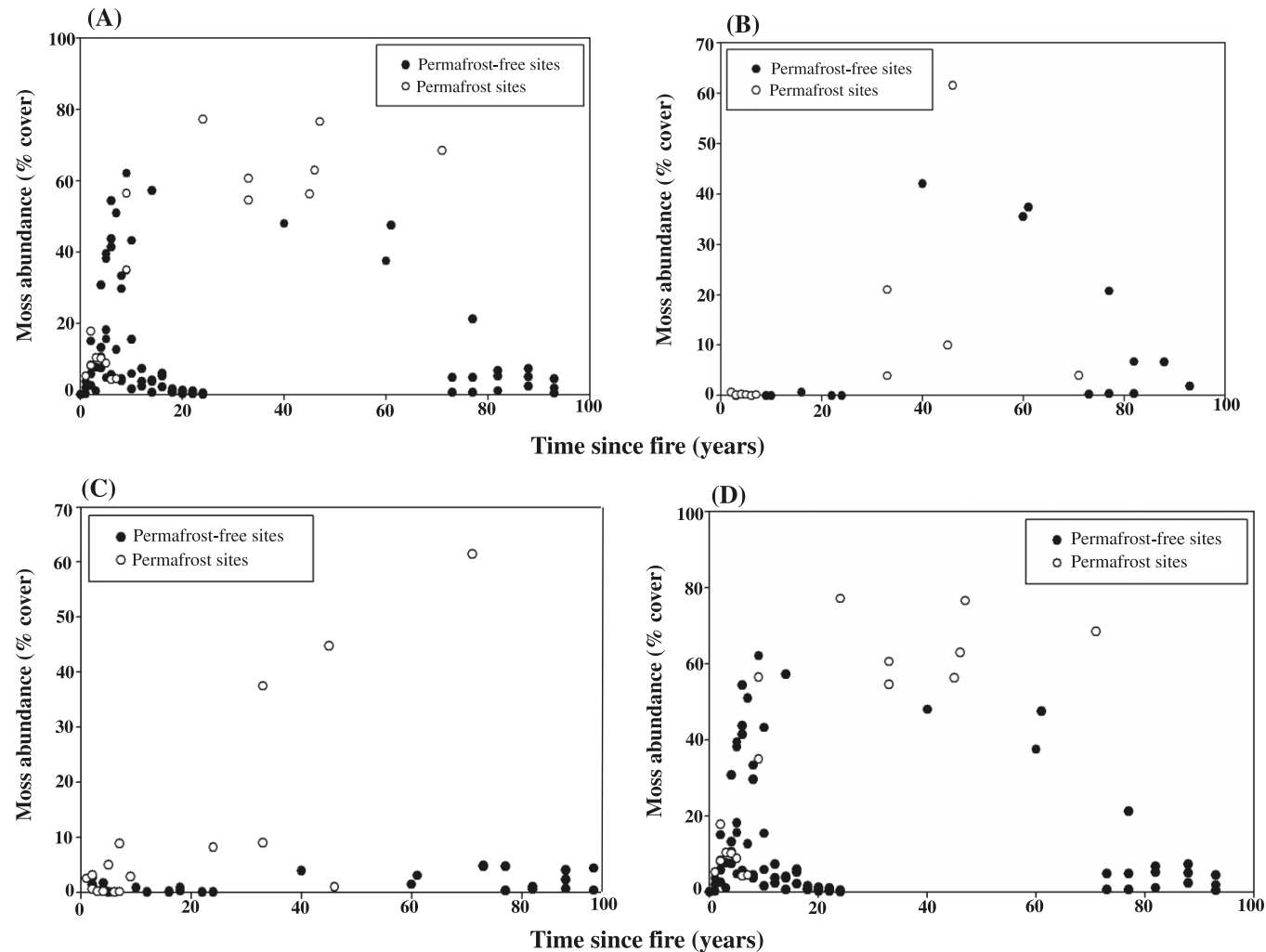
Moss net primary production (NPP) was not related to black spruce aboveground NPP (ANPP) in any landscape position but was related to understory ANPP in upland sites

**Table 1.** Diversity indices and moss abundance across successional stages in the uplands and floodplains.

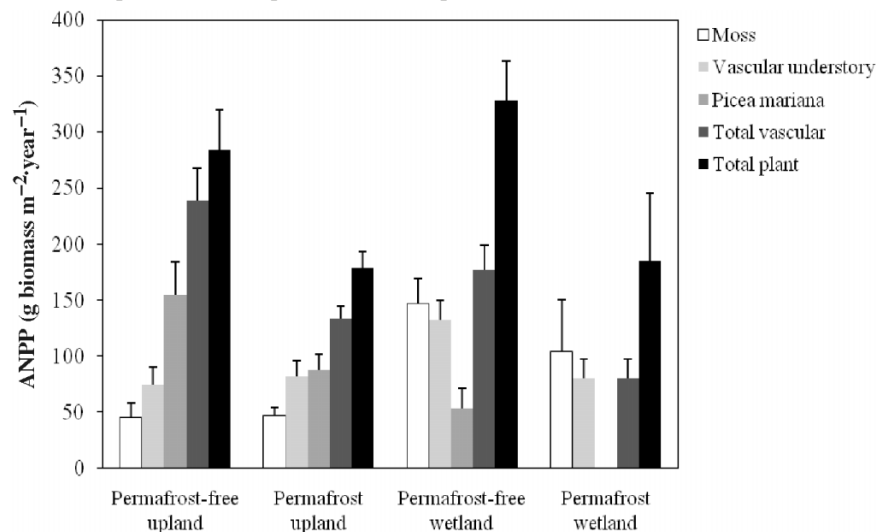
Site	Diversity				Moss Abundance (% cover)		
	<i>N</i>	Alpha	Beta	Gamma	Colonizer spp.	Feather mosses	<i>Sphagnum</i>
Uplands							
UP1s	3	4	2.5	10	0.275a	0.09±0.14a	na
UP2s	3	3.7	1.1	4	na	2.90±2.16a	na
UP3s	3	6.7	1.3	9	0.01a	23.17±5.33a	3.26±0.05
UP4s	4	9.8	2.6	25	1.06±0.63a	61.58±12.94b	na
All sites		6	5.3	32			
Floodplains							
FP0s	3	2.7	1.9	5	8.53±3.31a	0.225a	na
FP1s	3	4.0	2.3	9	1.38±0.97ab	0.11±0.42a	na
FP2s	3	6.3	2.1	13	0.217±0.09b	1.43±0.28a	na
FP3s	3	8.3	1.8	15	0.18±0.05ab	22.70±14.09a	na
FP4s	3	9.7	1.6	15	0.63±0.38ab	50.46±13.04a	6.60±6.35
FP5s	4	10.7	2.9	31	0.14±0.07b	44.69±12.33a	na
All sites		6.9	7.8	54			

**Note:** Values followed by the same letter denote nonsignificant post hoc comparisons among means. Missing data are denoted with “na”.

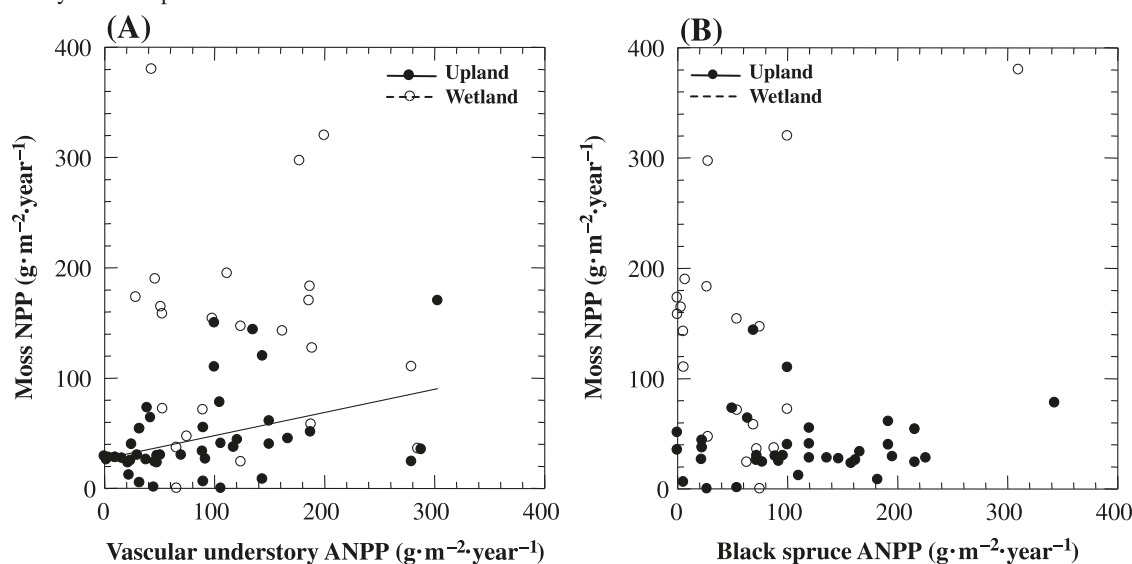
**Fig. 2.** Abundance of mosses with time since fire for (A) all moss species, (B) colonizer species, (C) other true moss species, and (D) feather mosses species. Data are categorized by permafrost status.



**Fig. 3.** Compiled rates of ANPP for permafrost and permafrost-free upland and wetland sites (means  $\pm$  1 SE).



**Fig. 4.** (A) The relationship between understory vascular and moss NPP was significant for uplands ( $r = 0.50$ ,  $p = 0.001$ ) but not for wetlands ( $r = 0.08$ ,  $p = 0.71$ ). (B) The relationship between black spruce (*Picea mariana*) and moss NPP was not significant for either uplands or wetlands. Analyses were performed on transformed moss NPP data but are shown on a raw scale.

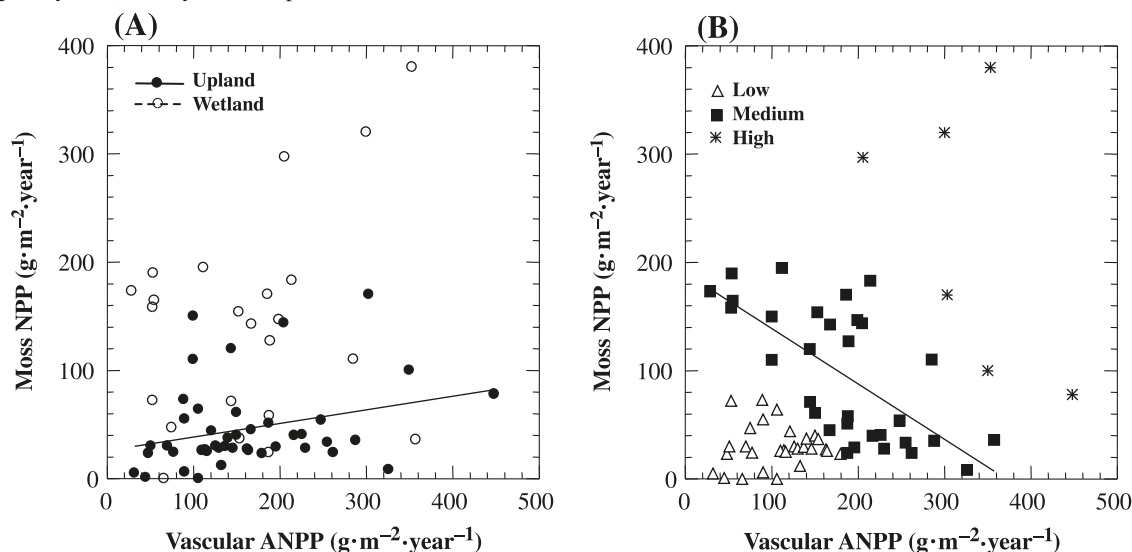


primarily because of the strong relationship between these variables in tundra ( $r = 0.62$ ,  $p = 0.03$ ) (Fig. 4). Moss productivity was positively correlated with total vascular ANPP in upland but not in wetland sites (Fig. 5). The hypothesis that moss productivity is often similar to or greater than black spruce ANPP was supported for the forested wetlands represented in our study but rejected for the upland sites, where moss productivity tended to be less than half of black spruce productivity (Appendix A, Table A1). Seventy-five percent of the wetland sites had greater moss than black spruce productivity, which is significantly more than would be expected based on a null model ( $\chi^2 = 4.00$ ,  $p = 0.05$ ). Within these wetland sites, mosses contributed 53% and 58% of total site ANPP in fens and bogs, respectively. However, among upland sites, the majority (74%) of permafrost and permafrost-free forest sites had more black spruce than moss productivity ( $\chi^2 = 6.26$ ,  $p = 0.01$ ). Mosses contributed 25% and 14% of total site ANPP in permafrost and permafrost-free uplands, respectively.

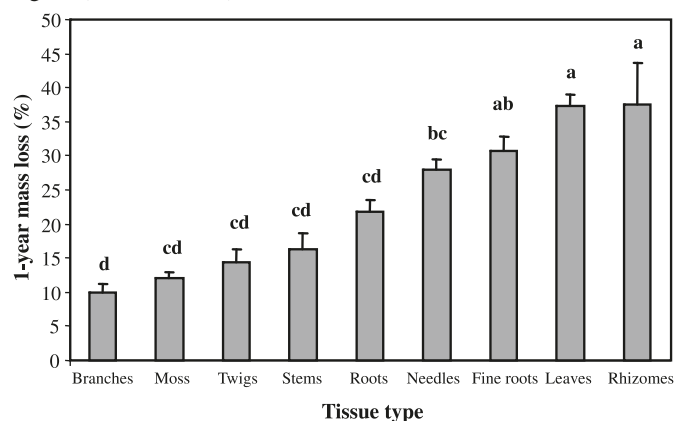
#### Moss and vascular tissue decomposition

Rates of litter mass loss varied among plant organs and tissue type ( $F_{[7,203]} = 3.53$ ,  $p = 0.001$ ), with no differences among landscape positions or interaction between plant organ and landscape position. Mass loss rates also did not vary among vascular growth forms. Mass loss rates averaged  $26.2 \pm 1.3\%$  in lowlands and  $25.3 \pm 1.3\%$  in uplands. Rhizomes, leaves, and fine roots corresponded to the fastest decomposition rates, with average 1-year mass losses exceeding 30% (Fig. 6). As expected, moss tissue decomposed more slowly than vascular photosynthetic tissue. Surprisingly, the hypothesis that woodier tissues such as branches would decompose more slowly than mosses was not supported by these data, as there were no differences in mass loss rates between moss and woody tissues such as stems and twigs. Only branches (with a mean mass loss of  $10.0 \pm 1.1\%$ ) had slower rates of mass loss than moss, which averaged  $12.1 \pm 0.8\%$  (Fig. 6).

**Fig. 5.** (A) The relationship between total vascular and moss NPP was significant for uplands ( $r = 0.33$ ,  $p = 0.03$ ) but not for wetlands ( $r = 0.22$ ,  $p = 0.31$ ). (B) The relationship between total vascular and moss NPP was significant only for intermediate-productivity sites ( $r = -0.67$ ,  $p < 0.001$ ) and was not significant for the low- ( $r = 0.28$ ,  $p = 0.14$ ) or high- ( $r = -0.65$ ,  $p = 0.16$ ) productivity sites. Productivity classes are based on site differences in moss plus vascular ANPP (low:  $<200 \text{ g}\cdot\text{m}^{-2}\cdot\text{year}^{-1}$ , medium:  $200\text{--}400 \text{ g}\cdot\text{m}^{-2}\cdot\text{year}^{-1}$ , high:  $>400 \text{ g}\cdot\text{m}^{-2}\cdot\text{year}^{-1}$ ). Analyses were performed on transformed moss NPP data but are shown on a raw scale.



**Fig. 6.** Compiled mass loss rates across moss and vascular plant organs (means  $\pm 1$  SE).



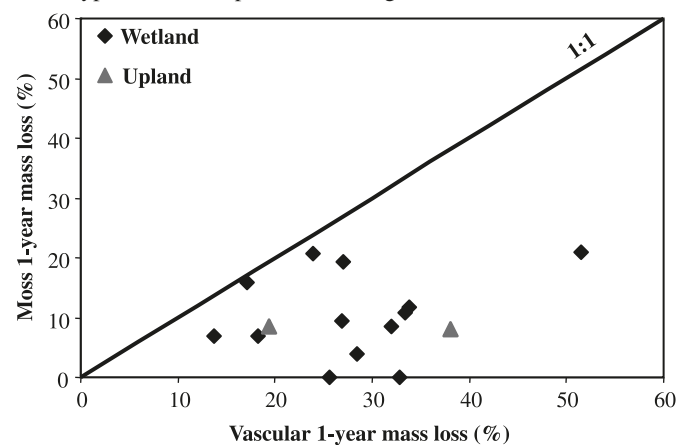
Mass loss rates of moss tissue varied among moss groups ( $F_{[4,78]} = 6.99$ ,  $p = 0.001$ ), with no interaction between moss group and landscape position. Mean mass losses were  $8.6 \pm 2.2\%$ ,  $8.7 \pm 1.5\%$ ,  $9.2 \pm 0.1\%$ ,  $15.2 \pm 1.9\%$ , and  $17.2 \pm 1.4\%$  for *Sphagnum* section *Sphagnum*, *Sphagnum* section *Acutifolia*, true mosses, feather mosses, and *Sphagnum* section *Cuspidata*, respectively. We compared moss versus vascular litter decomposition rates for the subset of studies that included both litter types in their design. All mass loss data from these studies fell below the 1:1 line, showing that moss litter consistently decomposes more slowly than vascular litter across both upland and wetland sites (Fig. 7).

## Discussion

### Moss succession and changing disturbance regimes in interior Alaska

Sites in the BNZ-LTER floodplain and forest successional

**Fig. 7.** Relationship between moss and vascular litter mass loss rates for a subset of decomposition studies that included both plant tissue types in their experimental design.



sequences were selected to represent “turning points” in boreal ecosystem succession, largely in terms of changing forest canopy structure. In our analysis of data from the successional sequences, we were particularly interested in whether changes in moss abundance and composition reflected a consistent successional trajectory across primary (flooding) and secondary (wildfire) succession. In both the floodplain and upland sites, total moss abundance and richness tended to increase across the LTER successional stages, likely as a result of the development of more stable soil surfaces and hydrological regimes that favor moss proliferation. The primary succession floodplain sites tended to have higher species richness but greater variation in moss abundance relative to the secondary succession upland sites. Frequent hydrologic disturbances that characterize Alaskan floodplains likely create a wider array of niches supporting higher levels of diversity than in upland forests. However, it also seems likely that variable hydrologic regimes limit fur-

ther proliferation of a ground-layer moss community and may be responsible for why mosses did not exceed 50% cover in the floodplain successional sequence. Given that moss populations likely are adapted to more unstable hydrologic regimes in floodplains than in uplands, and given the larger species pools (at least in the mature floodplain sites), mosses may be more resilient to perturbations in floodplain than in upland forest communities.

We used a larger data set to examine more detailed patterns of moss succession post-fire in Alaskan forests with and without surface permafrost. Wildfire generally represents the most common stand-replacing disturbance in boreal forests. In western Canadian bogs, post-fire moss succession tends to follow three well-constrained phases (Benscoter 2006; Benscoter and Vitt 2008) in which *Sphagnum* spp. displace colonizer moss species such as *Polytrichum strictum* within the first 5–10 years after fire, remaining dominant for more than 80 years until black spruce canopy closure allows feather mosses to become more competitive. *Sphagnum* and feather moss species have very different photosynthetic relationships with both light and moisture. While *Sphagnum* spp. outcompete feather mosses in high light and wet soil conditions, feather mosses become stronger competitors with *Sphagnum* in sites with a higher level of canopy closure (e.g., Swanson and Flanagan 2001). Similar to Canadian bogs, our results for Alaskan forests appear to support three distinct phases of moss succession following wildfire. Colonizer species in the Alaskan forests peaked within the first decade post-fire in permafrost-free sites and within approximately 35 years post-fire in permafrost sites. However, while the Alberta bogs supported a stable *Sphagnum* community from approximately 10 to 80 years post-fire, *Sphagnum* was present in the Alaskan sites only in late successional stands and in very low abundances. Instead, feather mosses and other true moss species tended to drive moss successional change after about 20 years post-fire. While black spruce canopy closure and feather moss proliferation in Alberta bogs occur after a long and stable period of *Sphagnum* dominance (Benscoter and Vitt 2008), the development of a black spruce canopy in Alaskan forests occurs either relatively quickly post-fire or following a hardwood phase of succession, as depicted by the upland BNZ-LTER chronosequence sites (Van Cleve et al. 1983). Coniferous dominance and canopy closure are accompanied by decreased light availability and decreased litterfall, facilitating the expansion of feather mosses.

In general, our results suggest that moss succession in Alaskan forests is variable and depends on the type of succession (primary versus secondary) and the microhabitat conditions post-disturbance (e.g., permafrost soils versus permafrost-free soils). For example, while colonizer species tended to peak in abundance in the first and third decade post-fire in permafrost-free and permafrost sites, respectively, many early-successional sites had very low abundances of these pioneer species. It seems likely that this variation is related to the severity of organic soil combustion during fire activity. We suggest that particularly after severe burning, pioneer species are likely to play an important role in stabilizing the charcoal layer, promoting water retention in the surface soil, and facilitating the colonization of less stress-tolerant species. There also was high variation in

moss abundance in mid-successional stands (e.g., 30–80 years post-fire), driven primarily by variation in feather moss cover. Feather moss proliferation is dependent on canopy cover and light conditions, which also would be affected by fire severity and resulting patterns of tree regrowth.

Currently, over 40% of boreal Alaska is covered in black spruce forests (Van Cleve et al. 1983). However, the distribution of black spruce forests almost certainly will be affected by ongoing changes in Alaska's fire regime. The fire return interval in interior Alaska has decreased largely over the past decade (Kasischke et al. 2010). If climate change and accelerated fire cycles increase the spatial abundance of ecosystems similar in plant composition to these mid-successional forests and decrease the abundance of late-successional forests, the role of feather mosses in boreal ecosystem function is likely to become more important, while the role of *Sphagnum* species would decrease. While we were not able to examine the effects of stand age, our productivity synthesis revealed little variation in feather moss productivity in upland sites (mean rate of approximately 49 g·m<sup>-2</sup>·year<sup>-1</sup>). The productivity of this moss group, however, was low relative to that of *Sphagnum* spp. Thus, increases in feather moss abundance over *Sphagnum* cover are likely to reduce forest floor productivity and also will impact several other important ecosystem functions such as ecosystem N fixation (see section below).

As peat layers develop over time in Alaskan forests, the aggradation of permafrost leads to increases in soil moisture and thinning of the black spruce canopy and consequently, *Sphagnum* is able to outcompete feather moss species. This linkage between permafrost, organic soil, and moss succession likely explains why *Sphagnum* was found only in late-successional and permafrost sites. However, the low abundances of *Sphagnum* in our data set are not representative of interior Alaska, as *Sphagnum* can be a dominant ground-layer component in many forested and nonforested ecosystems in Alaska (e.g., Hollingsworth et al. 2006; Myers-Smith et al. 2008). Nonetheless, it seems likely that increases in fire activity that decrease the fire-free period in Alaska will reduce the likelihood of peat and *Sphagnum* recovery on the forest floor.

The role of mosses in ecosystem succession is likely to be affected by interactions between directional climate change and climate-mediated disturbances such as wildfire. Higher nutrient availability in warmer and more oxic soil conditions is expected to favor vascular plants at the expense of mosses, which tend to be adapted to nutrient-poor conditions. Increased vascular biomass and litter production can also inhibit moss growth by shading and (or) burial (Van Wijk et al. 2003). Such shifts in vascular species composition at the expense of mosses (but see productivity results below) will influence fuel loading and flammability, with potential consequences for fire frequency and severity.

### Effects of moss succession on aspects of ecosystem C and N cycling

Many ecosystem models incorporate information on interactions between plant traits and environmental resources and how these interactions affect resource competition and nutrient cycling. Recently, models have started to incorporate



moss as a single plant functional type, reflecting an increased awareness that mosses can have strong influences on ecosystem productivity and resource supply. Thus, there is a great need for research on the functional significance of moss at the ecosystem level to rationalize how mosses should be incorporated into modeling frameworks. Our synthesis of tundra, boreal forest, and wetland productivity indicates that, on average, mosses contributed to about 20% and 48% of ecosystem productivity in uplands and wetlands, respectively. Total site aboveground productivity tended to be higher in wetlands than in upland forests but was affected by the presence of permafrost, which tended to reduce aboveground productivity in both landscape positions. Because mosses contributed more to total aboveground productivity in wetlands than in upland forests, environmental change that leads to a reduction in moss abundance (i.e., changes in fire cycles and increased shading with vascular abundance) is likely to have larger impacts on wetland than on upland productivity. Environmental change that affects moss abundance will have broader consequences for northern ecosystem function than productivity alone, given that mosses influence decomposition rates and soil hydroclimate (see below).

Mosses have been thought to compensate for low vascular productivity in low-fertility and (or) low-oxygen sites (Goulden and Crill 1997). If this is true, then a major role of mosses in boreal ecosystem function might be to minimize spatial variation in ecosystem productivity across boreal landscapes. Surprisingly, our broad synthesis of productivity data did not reveal trade-offs between moss and vascular productivity either within or across the wetland and upland categories. Instead, we found positive relationships between moss and vascular aboveground productivity in upland sites and no relationship in wetland sites. These results suggest that, at least in upland sites, mosses and vascular plants are responding to similar patterns of resource availability, in that productive areas for vascular plants also serve as productive habitat for mosses. This finding has large implications for the resilience of boreal ecosystems, as environmental changes that effect plant niches could trigger simultaneous increases or decreases in vascular and nonvascular productivity. Instead of mosses compensating for low vascular productivity, climate change might instead exaggerate spatial variation in productivity at landscape scales.

Our results appear to contradict the results of several experimental studies that have suggested that warming and enhanced nutrient availability will favor vascular plants at the expense of mosses. For example, long-term water table drawdown studies in Finnish peatlands have shown that drier conditions shifted plant community structure from graminoids and mosses to woody vegetation over a 20-year period (Laiho et al. 2003). Long-term fertilization studies have found increases in vascular biomass that occurred at the expense of mosses and lichens, possibly due to shading and (or) burial by vascular litter, although osmotic stress might also be a factor (Cornelissen et al. 2001; Van Wijk et al. 2003; Dorrepaal 2007). While our synthesis was carried out at a broad spatial scale and focused primarily on mature sites, most experimental studies have altered resource availability within individual sites. There is additional evidence for local trade-offs between *Sphagnum* and black spruce

productivity across permafrost gradients in peatlands where high black spruce productivity (and low *Sphagnum* productivity due to shading) occurs in drier permafrost bogs and high *Sphagnum* productivity (and low black spruce productivity due to thermokarst and flooding) occurs in adjacent collapse scars (cf. Camill et al. 2001).

At local scales, there is relatively little variation in total site productivity and larger variation in how productivity is partitioned among plant community components such as mosses and trees. Our synthesis allowed us to investigate whether trade-offs between moss and tree productivity only occur in sites with similar total ANPP or whether these trade-offs also occur at larger scales that involve more variation in total site productivity. While there was no evidence of a trade-off between moss and vascular productivity across our data set, moss productivity was substantially higher in wetlands than in uplands, and vascular productivity was higher in uplands primarily due to black spruce contributions. We further divided our data set into three classes based on total site productivity (moss plus vascular ANPP) to determine whether trade-offs existed within sites with similar total production rates. While there were no relationships between moss and vascular NPP in the low- and high-productivity sites, there was a strong negative relationship between moss and vascular NPP in the intermediate-productivity sites (see Fig. 5B). We suggest that this is additional evidence that trade-offs between moss and vascular productivity occur across sites with little variation in total site productivity (such as at local spatial scales) but that these trade-offs do not persist at large spatial scales that involve increasing variation in productivity and resource availability.

Our synthesis of productivity data also revealed differences in moss NPP rates. Mean *Sphagnum* productivity was almost threefold greater than that of feather moss species. Changes in Alaska's fire regime that favor feather moss abundance at the expense of *Sphagnum* likely will result in overall declines in moss NPP. In some regions of the boreal region, *Sphagnum* often replaces feather moss through forest paludification (Fenton and Bergeron 2006). While *Sphagnum* colonization is likely to have strong effects on soil moisture and acidity, increases in *Sphagnum* abundance also likely will increase forest floor productivity. However, Benscoter and Vitt (2007) found that common methods for quantifying moss productivity could underestimate feather moss productivity by as much as 25%.

Because moss litter has been shown to decompose more slowly than vascular photosynthetic tissue (e.g., Hobbie et al. 2000; Lang et al. 2009), mosses have a strong influence on ecosystem C storage beyond their effects on productivity. Several mechanisms controlling the recalcitrance of moss biomass have been proposed, including high N use efficiency and low tissue N concentrations (Aerts et al. 1999), an abundance of phenolic compounds (Rasmussen 1994; Verhoeven and Liefveld 1997), and variation in carbohydrate chemistry (Turetsky et al. 2008; Hájek et al. 2010). Our synthesis compared mass loss rates of moss and vascular litters and found that moss mass loss rates were similar to those of woodier tissue such as branches and twigs. These results suggest that any environmental change that favors either woody material or mosses is likely to result in slow decomposition and nutrient turnover in boreal soils.

Several studies have quantified significant variation in decomposition rates among common moss species. In particular, studies from peatlands have shown that hummock-forming *Sphagnum*, typically within section *Acutifolia*, decompose more slowly than *Sphagnum* species that thrive in more low-lying microforms (section *Cuspidata*) (cf. Johnson and Damman 1991; Turetsky et al. 2008). Few studies, however, have compared decomposition rates among other moss groups (but see Lang et al. 2009). Our analyses found that *Sphagnum* spp. within section *Sphagnum* and *Acutifolia* decomposed more slowly than feather moss species and *Sphagnum* spp. within section *Cuspidata*. Lang et al. (2009) reported a wide range of mass loss values among feather moss species within experimental litter beds, yet feather moss tissue consistently decomposed more rapidly than *Sphagnum* tissue regardless of *Sphagnum* section. These results suggest that changes in moss community composition under drier climatic regimes could either increase or decrease decomposition rates on the forest or wetland floor, depending on whether successional trajectories favor increasing abundances of hummock-forming *Sphagnum* (slower decomposition) or feather mosses (faster decomposition). Alternatively, increases in inundation in boreal wetlands following permafrost degradation increase the abundance of *Sphagnum* spp. such as *Sphagnum riparium* and *S. angustifolium* (within section *Cuspidata*; Beilman 2001), which were associated with faster decomposition rates. However, because moss species in general tended to decompose more slowly than most vascular tissues, shifts in moss community composition may be less important in influencing decomposition processes at the ecosystem scale than either increases or decreases in total moss abundance.

Together, our literature analyses show that feather mosses tend to be less productive and decompose more quickly than *Sphagnum* spp. and thus will contribute less to ecosystem C storage. However, feather mosses, in particular *P. schreberi*, provide significant inputs of N to ecosystems via symbiotic relationships with N-fixing cyanobacteria. Evidence of N fixation among *Sphagnum* spp. is mixed (reviewed in Turetsky 2003), and in general, *Sphagnum* tend to have low N requirements. Due to high rates of cation-exchange capacity, *Sphagnum* spp. also retain a significant amount of ecosystem N (Li and Vitt 1997), effectively lowering available N concentrations for other species. Ecosystem N inputs via feather moss biological N fixation were found to be more pronounced in late-succession stands than in recently disturbed settings (Zackrisson et al. 2004), suggesting that the effects of altered disturbance regimes on ecosystem N supply is likely to be mediated by the moss layer.

### Role of moss in regulating soil climate and boreal responses to permafrost thaw and wildfire

Climate warming in Alaska is anticipated to trigger soil moisture deficits (Hinzman et al. 2005), increase the frequency and severity of disturbances such as wildfire (Kasischke et al. 2010), and accelerate soil nutrient turnover. While there is increasing evidence of ongoing and rapid climate change in Alaska (Hinzman et al. 2005), evaluating the degree to which Alaskan ecosystems are resilient to such environmental change remains a major focus of the BNZ-LTER program (Chapin et al. 2010).

We argue that boreal ecosystems with a significant moss ground layer are more resistant to changes in soil temperature and moisture associated with directional climate change compared with ecosystems with low moss cover. Accumulating moss biomass on the forest floor serves as a thermal buffer between the atmosphere, soils, and permafrost. In summer months, thicker organic layers coincide with cooler surface temperatures (Harden et al. 2006) due to the dramatic contrast in thermal properties between organic and mineral soils (Lachenbruch 1994; O'Donnell et al. 2009). While some moss species (particularly hummock-forming *Sphagnum*) have structural and physiological traits that promote high water retention, porosities of organic matter are high (Yi et al. 2009) and drainage occurs once the seasonal ice has thawed. Thus, in summer, dry surface conditions further promote the protection of permafrost by moss cover. Additionally, by producing significant amounts of biomass that decomposes slowly, mosses drive the formation of vertically accumulating peat layers, both in peatlands and in many upland boreal forests. Thick peat layers further buffer soil environments from fluctuating temperature and moisture, protecting ice lenses and promoting permafrost stability (Romanovski et al. 2008). Thus, there are important feedbacks between moss cover, moss productivity and decomposition, peat accumulation, and permafrost stability that would be disrupted with the loss of a moss layer, particularly the loss of *Sphagnum* spp.

Moss cover on the forest floor has a strong influence on the spatial patterns and overall severity of combustion during boreal wildfires. In general, ground-layer fuels dominate combustion during many boreal wildfires, with thick layers of live moss and dead moss tissue serving as an important fuel type (Amiro et al. 2001). Due to its low bulk density, feather moss biomass can dry out quickly and serve as flammable fuels. *Sphagnum* mosses, particularly species that form hummocks such as *S. fuscum*, have high water retention due to a dense canopy structure, efficient wicking ability (Rydin and McDonald 1985), and slow decomposition rates that maintain macropore structure over time (Turetsky et al. 2008). Thus, while the mosses in hummocks exist farther from the water table than in hollows, these microforms tend to have higher surface soil moisture contents. During periods of drought, high water retention in hummocks can have an important influence on vascular stress and survival. *Sphagnum* hummocks also tend to be the last ground-layer fuels to combust, often escaping deep burning during boreal wildfires (Shetler et al. 2008; Johnstone 2010). This resistance to burning creates “*Sphagnum* sheep” (unburned *Sphagnum* hummocks interspersed within charred hollows and flat microforms) that play an important role in post-fire soil C storage (Shetler et al. 2008).

Decreases in total moss abundance are predicted to occur as accelerated nutrient availability favors vascular growth and increases shading of the moss layer. Increased soil moisture deficits also are likely to trigger declines in moss abundance but may trigger community shifts favoring drought tolerators. However, climate change and its consequences for disturbances such as wildfire also will affect forest floor succession and resulting changes in moss community composition. A decrease in Alaska's fire period is likely to favor feather moss abundance over *Sphagnum* (see

Fig. 2). This community shift will reduce soil moisture retention (via lower bulk density and reduced capillary pressure), decrease peat accumulation (via decreased soil moisture, reduced productivity, and possibly increased decomposition rates), and increase ecosystem N fixation. Community shifts that favor feather moss over *Sphagnum* also are likely to be associated with increases in fuel combustion rates and deeper burning, which in turn will influence peat accumulation, permafrost stability, and post-fire regeneration (Johnstone et al. 2010).

## Conclusions

Here, we show that moss succession in Alaskan forests is variable, with feather moss proliferation driving much of the change after 20 years post-fire. Mosses contribute a large component of total aboveground productivity, particularly in boreal wetlands, and produce recalcitrant biomass that decomposes more slowly than a variety of vascular tissues. Because moss biomass insulates soil and permafrost layers and can have high water holding capacity, mosses contribute to boreal ecosystem resistance to directional climate change and climate-mediated disturbances such as permafrost thaw and wildfire. The loss of a moss layer with increasing soil moisture deficits or shading associated with increasing vascular abundance is likely to trigger threshold responses for multiple ecosystem functions, given the strong effects of moss on soil moisture and temperature, permafrost stability, forest floor combustion, and ecosystem C and N storage. Differences in moss traits such as water retention, productivity, litter quality and decomposition, and N retention and fixation among moss species and functional groups have important implications for ecosystem function but are not well understood. The effects of mosses on ecosystem functioning and their role in the resilience of boreal ecosystems and landscapes to changing climate and disturbance regimes will continue to be a growing area of research in the BNZ-LTER program.

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## Appendix A

Tables A1, A2, and A3 appear on the following pages.

**Table A1.** Site names, fire characteristics, and environmental characteristics of upland forest sites used for post-fire succession trajectories analysis.

Site name	Fire name	Year of burn	Measurement year(s)	Topography	Successional trajectory	Permafrost
DFTC	Granite Creek	1940	2001	Upland	Conifer	Absent
DF87	Granite Creek	1987	2001	Upland	Conifer	Absent
DFTB	Donnelly Flats	1999	2001	Upland	Conifer	Absent
DF94	Hajdukovich Creek	1994	2001	Lowland	Conifer	Present
DFCB	Donnelly Flats	1999	2001	Lowland	Conifer	Present
DF56	Fort Greeley	1956	2001	Lowland	Conifer	Present
Braeburn lower	Fox Lake/Laberge	1998	2004	Upland	Conifer	Absent
Braeburn upper	Fox Lake/Laberge	1998	2004	Upland	Conifer	Absent
Pelly hillslope	Minto	1995	2004	Upland	Conifer	Absent
Pelly lowland	Minto	1995	2004	Lowland	Conifer	Present
TKN0052		~1929	2000	Lowland	Conifer	Present
TKN0125		~1955	2001	Lowland	Conifer	Present
TKN0204		~1962	2002	Upland	Conifer	Absent
TKN0209		~1942	2002	Upland	Conifer	Absent
TKN0236		~1969	2002	Lowland	Conifer	Present
HR1A	Frostfire	1998	2001–2008	Upland	Conifer	Absent
UP1A	Rosie Creek	1987	1984, 1985, 1987, 1988, 1991, 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2007	Upland	Mixed	Absent
UP1B	Rosie Creek	1987	1983–1985, 1987, 1998, 1991, 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2007	Upland	Mixed	Absent
UP1C	Rosie Creek	1987	1984, 1985, 1987, 1988, 1991, 1993, 1995, 1997, 1999, 2001, 2003, 2005, 2007	Upland	Mixed	Absent
UP2A		~1915	1988, 1992, 1997, 2003, 2008	Upland	Mixed	Absent
UP2B		~1915	1988, 1992, 1997, 2003, 2008	Upland	Mixed	Absent
UP2C		~1915	1988, 1992, 1997, 2003, 2008	Upland	Mixed	Absent
SL1A	Survey Line	2001	2002–2008	Lowland	Conifer	Absent
SL1B	Survey Line	2001	2002–2008	Lowland	Conifer	Present
Wickersham	Wickersham	1971	1980, 1995, 2004	Upland	Conifer	Present

**Note:** For more information on sites, see Harden et al. 2010 (DFTC, DF87, DFTB, DF94, DFCB, and DF56 sites), Johnstone 2006 (Braeburn and Pelly sites), Hollingsworth et al. 2006 (TKN sites), [www.lter.uaf.edu/data\\_b.cfm](http://www.lter.uaf.edu/data_b.cfm) (UP and SL sites), [www.lter.uaf.edu/data\\_b.cfm](http://www.lter.uaf.edu/data_b.cfm), and Bernhardt et al. 2010 (Wickersham sites).

**Table A2.** Compilation of surveyed studies that included estimates of both moss and vascular aboveground net primary production (ANPP) within boreal forest and tundra biomes.

Reference	Biome	Years since fire	Landscape position	Vegetation type	Permafrost	Moss type	Moss NPP method	Moss NPP	Understory ANPP	Picmar ANPP	Other tree ANPP	Total vascular ANPP	Total ANPP
Billings 1987	Boreal		Upland	Bog	1	S	1	24.3		77.3		77.3	101.6
Billings 1987	Boreal		Wetland	Fen	1	O	1	194.9	111.7			111.7	306.6
Bond-Lamberty et al. 2004	Boreal	3	Wetland	Black spruce	0	E	1		65.9			65.9	65.9
Bond-Lamberty et al. 2004	Boreal	3	Upland	Black spruce	0	E	1		106			106	106
Bond-Lamberty et al. 2004	Boreal	151	Upland	Black spruce	0	F	1	12	22.5	110.3		132.8	144.8
Bond-Lamberty et al. 2004	Boreal	6	Upland	Black spruce	0	F	1	37.3	117.6	22.6		140.2	177.5
Bond-Lamberty et al. 2004	Boreal	71	Upland	Black spruce	0	F	1	27.3	15.9	146.7		162.6	189.9
Bond-Lamberty et al. 2004	Boreal	12	Wetland	Black spruce	0	S	1	36.8	65.7	88.1		153.8	190.6
Bond-Lamberty et al. 2004	Boreal	151	Wetland	Black spruce	0	S	1	24	124.1	63.3		187.4	211.4
Bond-Lamberty et al. 2004	Boreal	71	Wetland	Black spruce	0	S	1	71.2	89.8	54.4		144.2	215.4
Bond-Lamberty et al. 2004	Boreal	20	Upland	Black spruce	0	F	1	33.5	89.2	165.9		255.1	288.6
Bond-Lamberty et al. 2004	Boreal	37	Upland	Black spruce	0	F	1	8.3	143.8	182.2		326	334.3
Bond-Lamberty et al. 2004	Boreal	37	Wetland	Black spruce	0	S	1	146.8	124.1	75.1		199.2	346
Bond-Lamberty et al. 2004	Boreal	12	Upland	Black spruce	0	F	1	143.7	135.2	69.4		204.6	348.3
Bond-Lamberty et al. 2004	Boreal	6	Wetland	Black spruce	0	S	1	110.3	279.3	5.9		285.2	395.5
Bond-Lamberty et al. 2004	Boreal	20	Wetland	Black spruce	0	S	1	297	177.5	28.1		205.6	502.6
Camill et al. 2001	Boreal	0	Upland	Black spruce	1	SF	1, 2	25.0	23.8	92.3		116.1	145.2
Camill et al. 2001	Boreal	0	Upland	Black spruce	1	SF	1, 2	23.1	21.5	158.1		179.6	197.8
Camill et al. 2001	Boreal	0	Upland	Black spruce	1	SF	1, 2	29.2	0	195.7		195.7	216.1
Camill et al. 2001	Boreal	0	Upland	Black spruce	1	SF	1, 2	39.9	24.89	191.9		216.7	252.1
Camill et al. 2001	Boreal	0	Wetland	Black spruce	0	S	1	173.2	28.8	0.1		28.8	202.0
Camill et al. 2001	Boreal	0	Wetland	Black spruce	0	S	1	158.0	52.7	0.3		53.1	211.1
Camill et al. 2001	Boreal	0	Wetland	Black spruce	0	S	1	164.6	51.4	3.6		54.9	219.5



Table A2 (continued).

Reference	Biome	Years since fire	Landscape position	Vegetation type	Permafrost	Moss type	Moss NPP method	Moss NPP	Understory ANPP	Picmar ANPP	Other tree ANPP	Total vascular ANPP	Total ANPP
Camill et al. 2001	Boreal	0	Wetland	Black spruce	0	S	1	189.7	46.4	7.1		53.6	243.3
Grigal 1985	Boreal	0	Wetland	Bog	0	S	1	320	200	100		300	620
Grigal 1985	Boreal	0	Wetland	Bog	0	S	1	380	43	310		353	733
Hobbie and Chapin 1998	Tundra	0	Upland	Moist acidic tundra	1	SF	2	51.1	187.5			187.5	238.6
Mack et al. 2008	Boreal	5	Upland	Black spruce	1	E	1	1	45			45	46
Mack et al. 2008	Boreal	10	Upland	Black spruce	1	F	1	23.2	48			48	60
Mack et al. 2008	Boreal	5	Upland	Black spruce	1	E	1	6.1	90			90	96
Mack et al. 2008	Boreal	49	Upland	Black spruce	1	F	1,2	26.6	92	22		114	131
Mack et al. 2008	Boreal	81	Upland	Black spruce	1	F	1,2	29.6	48	89		137	161
Mack et al. 2008	Boreal	121	Upland	Black spruce	1	F	1,2	40.6	106	120		226	253
Mack et al. 2008	Boreal	16	Upland	Black spruce	1	E	1	35.2	288	0		288.0	319.0
Oechel and Van Cleve 1986	Boreal	0	Upland	Black spruce	1	F	2	110		100		100	210
Oechel and Van Cleve 1986	Boreal	0	Upland	White spruce	0	F	2	100			350	350	450
Reader and Stewart 1972	Boreal	0	Wetland	Bog	0	S	1	36	285	72.4		357.4	393.4
Ruess et al. 2006	Boreal	0	Upland	Black spruce	1	F	1	73	39	50		89	162
Ruess et al. 2006	Boreal	0	Upland	White spruce	0	F	1	78	105	343		448	526
Schuur et al. 2007	Tundra	0	Upland	Moist acidic tundra	1	SF	1	30	70			70	100
Schuur et al. 2007	Tundra	0	Upland	Shrub tundra	1	SF	1	55	90			90	145
Schuur et al. 2007	Tundra	0	Upland	Shrub tundra	1	S	1	150	100			100	250
Shaver and Chapin 1991	Tundra	0	Upland	Heath tundra	1	O	3	5	32			32	37
Shaver and Chapin 1991	Tundra	0	Wetland	Wet sedge tundra	1	O	3	30	51			51	81
Shaver et al. 1996	Tundra	0	Wetland	Wet sedge tundra	1	O	3	47	75			75	122
Shaver et al. 1996	Tundra	0	Wetland	Fen	1	O	3	72	53			53	125

Table A2 (concluded).

Reference	Biome	Years since fire	Landscape position	Vegetation type	Permafrost	Moss type	Moss NPP method	Moss NPP	Understory ANPP	Picmar ANPP	Other tree ANPP	Total vascular ANPP	Total ANPP
Shaver et al. 1996	Tundra	0	Upland	Moist acidic tundra	1	SF	3	44	121			121	165
Shaver et al. 1996	Tundra	0	Upland	Shrub tundra	1	F	3	40	150			150	190
Shaver et al. 1996	Tundra	0	Upland	Heath tundra	1	SF	3	61	150			150	211
Shaver et al. 1996	Tundra	0	Upland	Shrub tundra	1	SF	3	45	167			167	212
Shaver and Chapin 1991	Tundra	0	Upland	Moist acidic tundra	1	SF	3	120	144			144	264
Shaver and Chapin 1991	Tundra	0	Upland	Shrub tundra	1	F	3	170	303			303	473
Szumigalski 1995	Boreal	0	Wetland	Bog	0	S	1	154	98.3	54.3	0	152.6	306.6
Szumigalski and Bayley 1997	Boreal	0	Wetland	Shrubby fen	0	O	1	127	189			189	316
Szumigalski 1995	Boreal	0	Wetland	Fen	0	O	1	142.5	162	5.6	81.4	167.6	391.5
Thormann 1995	Boreal	0	Wetland	Shrubby fen	0	O	1	58	188			188	246
Thormann 1995	Boreal	0	Wetland	Shrubby fen	0	O	1	170	186			186	356
Thormann 1995	Boreal	0	Wetland	Bog	0	S	1	183	187	27		214	397
Vogel et al. 2008	Boreal	0	Upland	Black spruce	1	F	1	26	38	72		110	136
Vogel et al. 2008	Boreal	0	Upland	Black spruce	1	F	1	30	30	96		126	156
Vogel et al. 2008	Boreal	0	Upland	Black spruce	1	F	1	28	10	120		130	158
Vogel et al. 2008	Boreal	0	Upland	Black spruce	1	F	1	64	42	64		106	170
Vogel et al. 2008	Boreal	0	Upland	Black spruce	1	F	1	28	10	136		146	174
Vogel et al. 2008	Boreal	0	Upland	Black spruce	1	F	1	26	2	162		164	190
Vogel et al. 2008	Boreal	0	Upland	Black spruce	0	F	1	28	4	226		230	258
Vogel et al. 2008	Boreal	0	Upland	Black spruce	0	F	1	24	46	216		262	286
Vogel et al. 2008	Boreal	0	Upland	Black spruce	0	F	1	54	32	216		248	302

**Note:** Years since fire is indicated if reported. The absence of permafrost at a site is indicated by 0 and presence is indicated by 1. Moss types include *Sphagnum* spp. (S), feather moss species (F) (e.g., *Hylocomium splendens* and *Pleurozium schreberi*), early-successional colonizer moss species (E) (e.g., *Ceratodon purpureus* and *Politrichum* spp.), and other true moss species (O). Moss NPP methods were categorized as 1 for direct measurements of growth with cranked wire (Clymo 1970), fluorescent stain (Mack et al. 2008), or marked branch methods (Ruess et al. 2003), 2 for morphological marker methods that were calibrated to the site (e.g., Hobbie and Chapin 1998), and 3 for morphological marker methods that were from other sites (e.g., Shaver et al. 1996). Tree productivity was for black spruce (*Picea mariana*) unless otherwise noted.

**Table A3.** Compilation of mass loss rates of plant tissues in northern forests and wetlands.

Reference	Landscape position	Species	Plant organ	% mass loss	Vascular growth form	Moss group	Notes
Berg and Ekbohm 1991	Upland	<i>Bet pub</i>	Leaves	40.9	Deciduous		Reported in Hobbie et al. 2000
Berg and Ekbohm 1991	Upland	<i>Bet pub</i>	Leaves	43.0	Deciduous		Reported in Hobbie et al. 2000
Berg and Ekbohm 1991	Upland	<i>Pin cont</i>	Needles	22.5	Evergreen		Reported in Hobbie et al. 2000
Berg and Ekbohm 1991	Upland	<i>Pin syl</i>	Needles	29.4	Evergreen		Reported in Hobbie et al. 2000
Berg and Ekbohm 1991	Upland	<i>Pin syl</i>	Needles	31.1	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	11.1	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	17.4	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	17.9	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	19.8	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	25.9	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	30.0	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	30.7	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	35.2	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	36.3	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	36.4	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	36.9	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	38.1	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	42.0	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	42.2	Evergreen		Reported in Hobbie et al. 2000
Berg et al. 1993	Upland	<i>Pin syl</i>	Needles	43.7	Evergreen		Reported in Hobbie et al. 2000
Coulson and Butterfield 1978	Lowland	<i>Cal vul</i>	Leaves	25.6	Herbaceous		Fine-mesh bags on peat soils
Coulson and Butterfield 1978	Lowland	<i>Fes ovi</i>	Leaves	32.3	Herbaceous		Course mesh on peat soils
Coulson and Butterfield 1978	Lowland	<i>Fes ovi</i>	Leaves	36.2	Herbaceous		Fine-mesh bags on peat soils
Coulson and Butterfield 1978	Lowland	<i>Eri vag</i>	Leaves	39.9	Herbaceous		Fine-mesh bags on peat soils
Coulson and Butterfield 1978	Lowland	<i>Eri vag</i>	Leaves	43.6	Herbaceous		Fine-mesh bags on peat soils
Coulson and Butterfield 1978	Lowland	<i>Eri vag</i>	Leaves	44.2	Herbaceous		Course mesh on peat soils
Coulson and Butterfield 1978	Lowland	<i>Cal vul</i>	Leaves	48.4	Herbaceous		Course mesh on peat soils
Coulson and Butterfield 1978	Lowland	<i>Phl pra</i>	Leaves	48.9	Herbaceous		Course mesh on peat soils
Coulson and Butterfield 1978	Lowland	<i>Phl pra</i>	Leaves	54.4	Herbaceous		Fine-mesh bags on peat soils
Coulson and Butterfield 1978	Lowland	<i>Phl pra</i>	Leaves	57.1	Herbaceous		Course mesh on peat soils
Coulson and Butterfield 1978	Lowland	<i>Phl pra</i>	Leaves	60.9	Herbaceous		Fine-mesh bags on peat soils
Coulson and Butterfield 1978	Lowland	<i>Eri vag</i>	Leaves	70.8	Herbaceous		Course mesh on peat soils
Coulson and Butterfield 1978	Lowland	<i>Sph rec</i>	Moss	14.2	<i>Cuspidata</i>		Course mesh on peat soils
Coulson and Butterfield 1978	Lowland	<i>Sph rec</i>	Moss	16.2	<i>Cuspidata</i>		Fine-mesh bags on peat soils
Dorrepaal et al. 2005	Lowland	<i>Cal lapp</i>	Leaves	45.4	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Car rot</i>	Leaves	31.5	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Car vag</i>	Leaves	38.4	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Eri vag</i>	Leaves	18.3	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Tri ces</i>	Leaves	34.1	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Arc alp</i>	Leaves	45.3	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Bet nan</i>	Leaves	25.3	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sal lap</i>	Leaves	28.2	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sal myr</i>	Leaves	43.0	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds

Table A3 (continued).

Reference	Landscape position	Species	Plant organ	% mass loss	Vascular growth form	Moss group	Notes
Dorrepaal et al. 2005	Lowland	<i>Vac uli</i>	Leaves	32.4	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Bar alp</i>	Leaves	49.7	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Bis viv</i>	Leaves	30.3	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Rub cha</i>	Leaves	39.4	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sau alp</i>	Leaves	54.9	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sax aiz</i>	Leaves	18.5	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Car las</i>	Leaves	34.8	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Car ros</i>	Leaves	50.4	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Eri ang</i>	Leaves	14.3	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Mol cae</i>	Leaves	35.0	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Rhy alb</i>	Leaves	17.3	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Bet pub</i>	Leaves	35.3	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Myr gal</i>	Leaves	13.6	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sal pen</i>	Leaves	31.5	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sor auc</i>	Leaves	33.5	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Vac myr</i>	Leaves	15.2	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Epi pal</i>	Leaves	28.6	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Fil ulm</i>	Leaves	37.1	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Iri pse</i>	Leaves	45.1	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Nar oss</i>	Leaves	46.1	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sta pal</i>	Leaves	39.2	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Cal can</i>	Leaves	62.0	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Car acu</i>	Leaves	47.8	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Jun sub</i>	Leaves	80.4	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Phr aus</i>	Leaves	48.7	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sch lac</i>	Leaves	53.6	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Aln glu</i>	Leaves	28.3	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Aro prun</i>	Leaves	76.4	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Lon per</i>	Leaves	98.8	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Rub fru</i>	Leaves	82.6	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sal cin</i>	Leaves	52.6	Deciduous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Ang syl</i>	Leaves	96.5	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Cal pal</i>	Leaves	91.2	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Cha ang</i>	Leaves	99.0	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Cir pal</i>	Leaves	92.9	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Hyd vul</i>	Leaves	98.2	Herbaceous		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph bal</i>	Moss	9.5		<i>Cuspidata</i>	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph fus</i>	Moss	4.2		<i>Acutifolia</i>	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph rip</i>	Moss	25.5		<i>Cuspidata</i>	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph war</i>	Moss	4.5		<i>Acutifolia</i>	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph ang</i>	Moss	18.5		<i>Cuspidata</i>	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph cus</i>	Moss	8.9		<i>Cuspidata</i>	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph mag</i>	Moss	5.1		<i>Sphagnum</i>	8-month mass loss on experimental <i>Sphagnum</i> beds



Table A3 (continued).

Reference	Landscape position	Species	Plant organ	% mass loss	Vascular growth form	Moss group	Notes
Dorrepaal et al. 2005	Lowland	<i>Sph pap</i>	Moss	1.2		<i>Sphagnum</i>	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph rub</i>	Moss	8.8		<i>Acutifolia</i>	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph con</i>	Moss	−5.0		Subsecunda	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph fal</i>	Moss	13.3		<i>Cuspidata</i>	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph pal</i>	Moss	−5.5		<i>Sphagnum</i>	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph squ</i>	Moss	3.8		Squarossa	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Sph sub</i>	Moss	−5.3		<i>Acutifolia</i>	8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>And pol</i>	Needles	27.1	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Emp nig</i>	Needles	33.6	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Jun com</i>	Needles	33.4	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Rho lapp</i>	Needles	26.5	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Vacc vit</i>	Needles	12.6	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>And pol</i>	Needles	34.7	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Cal vul</i>	Needles	28.4	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Led pal</i>	Needles	23.1	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Pic abi</i>	Needles	36.6	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Pin syl</i>	Needles	40.9	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Cal vul</i>	Needles	53.8	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Eri tet</i>	Needles	52.7	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Led gro</i>	Needles	30.5	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Pin syl</i>	Needles	47.5	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Dorrepaal et al. 2005	Lowland	<i>Vac vit</i>	Needles	32.7	Evergreen		8-month mass loss on experimental <i>Sphagnum</i> beds
Finér et al. 1997	Upland	<i>Abi bal</i>	Fine roots	22.2	Evergreen		
Finér et al. 1997	Upland	<i>Thu occ</i>	Fine roots	23.5	Evergreen		
Finér et al. 1997	Upland	<i>Thu occ</i>	Fine roots	23.7	Evergreen		
Finér et al. 1997	Upland	<i>Thu occ</i>	Fine roots	24.7	Evergreen		
Finér et al. 1997	Upland	<i>Abi bal</i>	Fine roots	25.3	Evergreen		
Finér et al. 1997	Upland	<i>Abi bal</i>	Fine roots	26.4	Evergreen		
Finér et al. 1997	Upland	<i>Pop trem</i>	Fine roots	28.6	Deciduous		
Finér et al. 1997	Upland	<i>Pop trem</i>	Fine roots	30.2	Deciduous		
Finér et al. 1997	Upland	<i>Pop trem</i>	Fine roots	33.5	Deciduous		
Flanagan and Van Cleve 1983	Upland	<i>Bet pap</i>	Leaves	24.0	Deciduous		Reported in Hobbie et al. 2000
Flanagan and Van Cleve 1983	Upland	<i>Bet pap</i>	Leaves	31.0	Deciduous		Reported in Hobbie et al. 2000
Flanagan and Van Cleve 1983	Upland	<i>Pic mar</i>	Needles	5.0	Evergreen		Reported in Hobbie et al. 2000
Flanagan and Van Cleve 1983	Upland	<i>Pic mar</i>	Needles	6.0	Evergreen		Reported in Hobbie et al. 2000
Grigal and McColl 1977	Upland	<i>Pop trem</i>	Leaves	41.1	Deciduous		Reported in Hobbie et al. 2000
Grigal and McColl 1977	Upland	<i>Abe mac</i>	Leaves	83.5	Deciduous		Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Car aqu</i>	Leaves	5.0	Herbaceous		Reported in Hobbie et al. 2000
Heal and French 1974	Upland	<i>Eri vag</i>	Leaves	5.0	Herbaceous		Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Eri ang</i>	Leaves	6.0	Herbaceous		Reported in Hobbie et al. 2000
Heal and French 1974	Upland	<i>Jun tri</i>	Leaves	7.0	Herbaceous		Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Dup fis</i>	Leaves	16.0	Herbaceous		Reported in Hobbie et al. 2000
Heal and French 1974	Upland	<i>Car big</i>	Leaves	20.0	Herbaceous		Reported in Hobbie et al. 2000

Table A3 (continued).

Reference	Landscape position	Species	Plant organ	% mass loss	Vascular growth form	Moss group	Notes
Heal and French 1974	Upland	<i>Car stan</i>	Leaves	20.0	Herbaceous		Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Rub cha</i>	Leaves	20.0	Deciduous		Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Bet nan</i>	Leaves	25.5	Deciduous		Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Sal</i> spp. shoots	Leaves	28.0	Deciduous		Reported in Hobbie et al. 2000
Heal and French 1974	Upland	<i>Bet nan</i>	Leaves	32.4	Deciduous		Reported in Hobbie et al. 2000
Heal and French 1974	Upland	<i>Rub cha</i>	Leaves	35.6	Deciduous		Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Car nig</i>	Leaves	41.0	Herbaceous		Reported in Hobbie et al. 2000
Heal and French 1974	Upland	<i>Ple sch</i>	Moss	8.0		Feather moss	Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Sph lin</i>	Moss	7.0			Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Sph rip</i>	Moss	10.0		<i>Cuspidata</i>	Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Sph fus</i>	Moss	0.0		<i>Acutifolia</i>	Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Sph rec</i>	Moss	5.0		<i>Cuspidata</i>	Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Sph bal</i>	Moss	6.0		<i>Cuspidata</i>	Reported in Hobbie et al. 2000
Heal and French 1974	Upland	Mixed moss	Moss	4.0			Reported in Hobbie et al. 2000
Heal and French 1974	Upland	Mixed moss	Moss	11.0			Reported in Hobbie et al. 2000
Heal and French 1974	Upland	Mixed moss	Moss	17.0			Reported in Hobbie et al. 2000
Heal and French 1974	Lowland	<i>Dre unc</i>	Moss	0.0		True moss	Reported in Hobbie et al. 2000
Heal and French 1974	Upland	<i>Dry oct</i>	Needles	6.0	Evergreen		Reported in Hobbie et al. 2000
Heal and French 1974	Upland	<i>Dry int</i>	Needles	8.0	Evergreen		Reported in Hobbie et al. 2000
Heal and French 1974	Upland	<i>Pin syl</i>	Needles	15.0	Evergreen		Reported in Hobbie et al. 2000
Heal and French 1974	Upland	<i>Vac spp</i>	Needles	24.0	Evergreen		Reported in Hobbie et al. 2000
Heal and French 1974	Upland	<i>Bet tor</i>	Stems	24.0	Deciduous		Reported in Hobbie et al. 2000
Hobbie and Chapin 1996	Upland	<i>Bet pap</i>	Leaves	24.0	Deciduous		Reported in Hobbie et al. 2000
Hobbie and Chapin 1996	Upland	<i>Bet pap</i>	Leaves	32.8	Deciduous		Reported in Hobbie et al. 2000
Huang and Schoenau 1997	Upland	<i>Pop trem</i>	Leaves	38.5	Deciduous		Reported in Hobbie et al. 2000
Huang and Schoenau 1997	Upland	<i>Cor cor</i>	Leaves	52.0	Deciduous		Reported in Hobbie et al. 2000
Johnson and Damman 1991	Lowland	<i>Sph cus</i>	Moss	19.4		<i>Cuspidata</i>	Reported in Hobbie et al. 2000
Johnson and Damman 1991	Lowland	<i>Sph fus</i>	Moss	11.4		<i>Acutifolia</i>	Reported in Hobbie et al. 2000
Laiho et al. 2004	Lowland	<i>Pin syl</i>	Fine roots	36.0	Evergreen		0–10 cm incubation only
Laiho et al. 2004	Lowland	<i>Pin syl</i>	Fine roots	40.0	Evergreen		
Laiho et al. 2004	Lowland	<i>Pin syl</i>	Fine roots	42.0	Evergreen		
Laiho et al. 2004	Lowland	<i>Pin syl</i>	Fine roots	44.0	Evergreen		
Laiho et al. 2004	Lowland	<i>Pin syl</i>	Needles	39.0	Evergreen		
Laiho et al. 2004	Lowland	<i>Pin syl</i>	Needles	39.0	Evergreen		
Laiho et al. 2004	Lowland	<i>Pin syl</i>	Needles	40.0	Evergreen		0–10 cm incubation only
Laiho et al. 2004	Lowland	<i>Pin syl</i>	Needles	45.0	Evergreen		
Laiho et al. 2004	Lowland	<i>Pin syl</i>	Roots	22.0	Evergreen		
Laiho et al. 2004	Lowland	<i>Pin syl</i>	Roots	25.0	Evergreen		
Laiho et al. 2004	Lowland	<i>Pin syl</i>	Roots	27.0	Evergreen		0–10 cm incubation only
Laiho et al. 2004	Lowland	<i>Pin syl</i>	Roots	28.0	Evergreen		
Larmola et al. 2006	Lowland	<i>Sph mag</i>	Moss	0.0		<i>Sphagnum</i>	
Larmola et al. 2006	Lowland	<i>Sph mag</i>	Moss	0.0		<i>Sphagnum</i>	
Larmola et al. 2006	Lowland	<i>Sph mag</i>	Moss	4.0		<i>Sphagnum</i>	

Table A3 (continued).

Reference	Landscape position	Species	Plant organ	% mass loss	Vascular growth form	Moss group	Notes
Larmola et al. 2006	Lowland	<i>Com pal</i>	Rhizomes	16.0	Herbaceous		
Larmola et al. 2006	Lowland	<i>Com pal</i>	Rhizomes	16.0	Herbaceous		
Larmola et al. 2006	Lowland	<i>Phr aus</i>	Rhizomes	33.0	Herbaceous		
Larmola et al. 2006	Lowland	<i>Phr aus</i>	Rhizomes	50.0	Herbaceous		
Larmola et al. 2006	Lowland	<i>Car aqu</i>	Rhizomes	52.0	Herbaceous		
Larmola et al. 2006	Lowland	<i>Phr aus</i>	Rhizomes	62.0	Herbaceous		
Larmola et al. 2006	Lowland	<i>Com pal</i>	Roots	19.0	Herbaceous		
Larmola et al. 2006	Lowland	<i>Phr aus</i>	Roots	24.0	Herbaceous		
Larmola et al. 2006	Lowland	<i>Com pal</i>	Roots	25.0	Herbaceous		
Larmola et al. 2006	Lowland	<i>Phr aus</i>	Roots	26.0	Herbaceous		
Larmola et al. 2006	Lowland	<i>Phr aus</i>	Roots	30.0	Herbaceous		
Moore 1984	Upland	<i>Pic mar</i>	Needles	13.1	Evergreen		Reported in Hobbie et al. 2000
Moore 1984	Upland	<i>Pic mar</i>	Needles	13.9	Evergreen		Reported in Hobbie et al. 2000
Moore 1984	Upland	<i>Pic mar</i>	Needles	15.6	Evergreen		Reported in Hobbie et al. 2000
Moore et al. 2007	Lowland	<i>Carex</i>	Leaves	10.5	Herbaceous		
Moore et al. 2007	Lowland	<i>Typha</i>	Leaves	11.1	Herbaceous		
Moore et al. 2007	Lowland	<i>Carex</i>	Leaves	15.9	Herbaceous		
Moore et al. 2007	Lowland	<i>Cha cal</i>	Leaves	18.7	Evergreen		
Moore et al. 2007	Lowland	<i>Cha cal</i>	Leaves	20.3	Evergreen		
Moore et al. 2007	Lowland	<i>Carex</i>	Leaves	22.1	Herbaceous		
Moore et al. 2007	Lowland	<i>Typha</i>	Leaves	24.0	Herbaceous		
Moore et al. 2007	Lowland	<i>Cha cal</i>	Leaves	24.2	Evergreen		
Moore et al. 2007	Lowland	<i>Typha</i>	Leaves	28.8	Herbaceous		
Moore et al. 2007	Lowland	<i>Cha cal</i>	Leaves	31.3	Evergreen		
Moore et al. 2007	Lowland	<i>Carex</i>	Leaves	32.2	Herbaceous		
Moore et al. 2007	Lowland	<i>Cha cal</i>	Leaves	34.0	Evergreen		
Moore et al. 2007	Lowland	<i>Typha</i>	Leaves	35.9	Herbaceous		
Moore et al. 2007	Lowland	<i>Carex</i>	Leaves	36.1	Herbaceous		
Moore et al. 2007	Lowland	<i>Typha</i>	Leaves	44.5	Herbaceous		
Moore et al. 2007	Lowland	<i>Sph ang</i>	Moss	14.1		<i>Cuspidata</i>	
Moore et al. 2007	Lowland	<i>Sph ang</i>	Moss	17.7		<i>Cuspidata</i>	
Moore et al. 2007	Lowland	<i>Sph ang</i>	Moss	18.8		<i>Cuspidata</i>	
Moore et al. 2007	Lowland	<i>Sph fal</i>	Moss	20.0		<i>Cuspidata</i>	
Moore et al. 2007	Lowland	<i>Sph ang</i>	Moss	0.0		<i>Cuspidata</i>	
Moore et al. 2007	Lowland	<i>Sph mag</i>	Moss	3.4		<i>Sphagnum</i>	
Moore et al. 2007	Lowland	<i>Sph cap</i>	Moss	14.0		<i>Acutifolia</i>	
Moore et al. 2007	Lowland	<i>Sph cap</i>	Moss	17.5		<i>Acutifolia</i>	
Moore et al. 2007	Lowland	<i>Sph cap</i>	Moss	21.0		<i>Acutifolia</i>	
Moore et al. 2007	Lowland	<i>Sph cap</i>	Moss	22.4		<i>Acutifolia</i>	
Moore et al. 2007	Lowland	<i>Cha cal</i>	Stems	9.1	Evergreen		
Moore et al. 2007	Lowland	<i>Cha cal</i>	Stems	10.1	Evergreen		
Moore et al. 2007	Lowland	<i>Cha cal</i>	Stems	14.6	Evergreen		
Moore et al. 2007	Lowland	<i>Cha cal</i>	Stems	19.1	Evergreen		

Table A3 (continued).

Reference	Landscape position	Species	Plant organ	% mass loss	Vascular growth form	Moss group	Notes
Moore et al. 2007	Lowland	<i>Cha cal</i>	Stems	20.5	Evergreen		
Nakatsubo et al. 1997	Upland	<i>Hyl spl</i>	Moss	12.1		Feather moss	Reported in Hobbie et al. 2000
Nakatsubo et al. 1997	Upland	<i>Hyl spl</i>	Moss	13.2		Feather moss	Reported in Hobbie et al. 2000
Prescott and Parkinson 1985	Upland	<i>Pin ban</i> × <i>Pin cont</i>	Needles	12.2	Evergreen		Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Car ros</i>	Leaves	22.0	Herbaceous		Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Cal can</i>	Leaves	23.1	Herbaceous		Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Sal ser</i>	Leaves	26.1	Deciduous		Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Sal beb</i>	Leaves	29.0	Deciduous		Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Ple sch</i>	Moss	24.7		Feather moss	Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Sph fus</i>	Moss	0.1		<i>Acutifolia</i>	Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Sph fus</i>	Moss	1.7		<i>Acutifolia</i>	Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Aul pal</i>	Moss	7.6		True moss	Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Aul pal</i>	Moss	8.9		True moss	Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Pol jan</i>	Moss	13.9	Moss	True moss	Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Led gro</i>	Needles	13.8	Evergreen		Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Led go</i>	Needles	17.8	Evergreen		Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Pic mar</i>	Needles	24.3	Evergreen		Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Led gro</i>	Needles	33.2	Evergreen		Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Pic mar</i>	Needles	33.7	Evergreen		Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Vac vit</i>	Needles	34.3	Evergreen		Reported in Hobbie et al. 2000
Reader and Stewart 1972	Lowland	<i>Vac vit</i>	Needles	00.7	Evergreen		Reported in Hobbie et al. 2000
Robinson et al. 1995	Upland	<i>Sal pol</i>	Leaves	12.7	Deciduous		Reported in Hobbie et al. 2000
Robinson et al. 1995	Upland	<i>Bet pub</i>	Leaves	23.6	Deciduous		Reported in Hobbie et al. 2000
Robinson et al. 1995	Upland	<i>Vac ulg</i>	Leaves	39.2	Deciduous		Reported in Hobbie et al. 2000
Rocheftort et al. 1990	Lowland	<i>Sph ang</i>	Moss	25.0		<i>Cuspidata</i>	Reported in Hobbie et al. 2000
Rocheftort et al. 1990	Lowland	<i>Sph fus</i>	Moss	12.0		<i>Acutifolia</i>	Reported in Hobbie et al. 2000
Rocheftort et al. 1990	Lowland	<i>Sph mag</i>	Moss	18.0		<i>Sphagnum</i>	Reported in Hobbie et al. 2000
Scheffer and Aerts 2000	Lowland	<i>Car las</i>	Rhizomes	23.0	Herbaceous		
Scheffer and Aerts 2000	Lowland	<i>Car las</i>	Rhizomes	29.0	Herbaceous		
Scheffer and Aerts 2000	Lowland	<i>Car dia</i>	Roots	9.0	Herbaceous		
Scheffer and Aerts 2000	Lowland	<i>Car las</i>	Roots	13.0	Herbaceous		
Scheffer and Aerts 2000	Lowland	<i>Car dia</i>	Roots	15.0	Herbaceous		
Scheffer and Aerts 2000	Lowland	<i>Car las</i>	Roots	23.0	Herbaceous		
Shaver et al. 1997	Upland	<i>Eri vag</i>	Leaves	12.9	Herbaceous		Reported in Hobbie et al. 2000
Shaver et al. 1997	Upland	<i>Rub cha</i>	Leaves	21.1	Deciduous		Reported in Hobbie et al. 2000
Shaver et al. 1997	Upland	<i>Bet nan</i>	Leaves	23.2	Deciduous		Reported in Hobbie et al. 2000
Shaver et al. 1997	Upland	<i>Pol bis</i>	Leaves	23.2	Deciduous		Reported in Hobbie et al. 2000
Shaver et al. 1997	Upland	<i>Sal pul</i>	Leaves	27.1	Deciduous		Reported in Hobbie et al. 2000
Shaver et al. 1997	Upland	<i>Sph spp</i>	Moss	12.4			Reported in Hobbie et al. 2000
Shaver et al. 1997	Upland	<i>Aul tur</i>	Moss	4.7		True moss	Reported in Hobbie et al. 2000
Shaver et al. 1997	Upland	<i>Led pal</i>	Needles	9.0	Evergreen		Reported in Hobbie et al. 2000
Thormann et al. 2001	Lowland	<i>Car aqu</i>	Leaves	37.6	Herbaceous		



Table A3 (continued).

Reference	Landscape position	Species	Plant organ	% mass loss	Vascular growth form	Moss group	Notes
Thormann et al. 2001	Lowland	<i>Sal pla</i>	Leaves	43.5	Deciduous		
Thormann et al. 2001	Lowland	<i>Sph fus</i>	Moss	18.1		<i>Acutifolia</i>	
Thormann et al. 2001	Lowland	<i>Car aqu</i>	Rhizomes	57.1	Herbaceous		
Thormann et al. 2001	Lowland	<i>Sal pla</i>	Roots	20.4	Deciduous		
Turetsky et al. 2008	Lowland	<i>Ple sch</i>	Moss	13.0		Feather moss	
Turetsky et al. 2008	Lowland	<i>Ple sch</i>	Moss	13.5		Feather moss	
Turetsky et al. 2008	Lowland	<i>Ple sch</i>	Moss	13.6		Feather moss	
Turetsky et al. 2008	Lowland	<i>Ple sch</i>	Moss	13.9		Feather moss	
Turetsky et al. 2008	Lowland	<i>Ple sch</i>	Moss	15.4		Feather moss	
Turetsky et al. 2008	Lowland	<i>Sph jen</i>	Moss	11.2		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph ang</i>	Moss	11.8		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph jen</i>	Moss	12.2		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph ang</i>	Moss	12.3		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph ang</i>	Moss	13.6		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph ang</i>	Moss	13.8		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph ang</i>	Moss	14.9		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph jen</i>	Moss	16.0		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph jen</i>	Moss	16.0		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph jen</i>	Moss	16.0		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph rip</i>	Moss	24.7		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph rip</i>	Moss	26.3		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph rip</i>	Moss	30.1		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph rip</i>	Moss	31.1		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph rip</i>	Moss	34.5		<i>Cuspidata</i>	
Turetsky et al. 2008	Lowland	<i>Sph fus</i>	Moss	4.6		<i>Acutifolia</i>	
Turetsky et al. 2008	Lowland	<i>Sph fus</i>	Moss	5.5		<i>Acutifolia</i>	
Turetsky et al. 2008	Lowland	<i>Sph fus</i>	Moss	8.0		<i>Acutifolia</i>	
Turetsky et al. 2008	Lowland	<i>Sph fus</i>	Moss	8.1		<i>Acutifolia</i>	
Turetsky et al. 2008	Lowland	<i>Sph fus</i>	Moss	8.8		<i>Acutifolia</i>	
Turetsky et al. 2008	Lowland	<i>Sph mag</i>	Moss	11.8		<i>Sphagnum</i>	
Turetsky et al. 2008	Lowland	<i>Sph mag</i>	Moss	12.6		<i>Sphagnum</i>	
Turetsky et al. 2008	Lowland	<i>Sph mag</i>	Moss	13.5		<i>Sphagnum</i>	
Turetsky et al. 2008	Lowland	<i>Sph mag</i>	Moss	19.0		<i>Sphagnum</i>	
Turetsky et al. 2008	Lowland	<i>Sph mag</i>	Moss	22.9		<i>Sphagnum</i>	
Turetsky et al. 2008	Lowland	<i>Sco sco</i>	Moss	4.9		True moss	
Turetsky et al. 2008	Lowland	<i>Sco sco</i>	Moss	8.8		True moss	
Turetsky et al. 2008	Lowland	<i>Tom nit</i>	Moss	9.2		True moss	
Turetsky et al. 2008	Lowland	<i>Tom nit</i>	Moss	9.9		True moss	
Turetsky et al. 2008	Lowland	<i>Tom nit</i>	Moss	10.3		True moss	
Turetsky et al. 2008	Lowland	<i>Sco sco</i>	Moss	10.5		True moss	
Turetsky et al. 2008	Lowland	<i>Tom nit</i>	Moss	10.9		True moss	
Turetsky et al. 2008	Lowland	<i>Sco sco</i>	Moss	12.3		True moss	
Turetsky et al. 2008	Lowland	<i>Tom nit</i>	Moss	12.8		True moss	

Table A3 (concluded).

Reference	Landscape position	Species	Plant organ	% mass loss	Vascular growth form	Moss group	Notes
Turetsky et al. 2008	Lowland	<i>Sco sco</i>	Moss	13.3		True moss	
M.R. Turetsky, unpublished	Upland	Birch	Leaves	21.0	Deciduous		
M.R. Turetsky, unpublished	Upland	Birch	Leaves	30.0	Deciduous		
M.R. Turetsky, unpublished	Upland	Birch	Leaves	43.0	Deciduous		
M.R. Turetsky, unpublished	Upland	<i>Ple sch</i>	Moss	10.0		Feather moss	
M.R. Turetsky, unpublished	Upland	<i>Ple sch</i>	Moss	33.0		Feather moss	
M.R. Turetsky, unpublished	Upland	<i>Ple sch</i>	Moss	7.0		Feather moss	
Van Cleve 1971	Upland	<i>Aln cris</i>	Leaves	37.1	Deciduous		Reported in Hobbie et al. 2000
Van Cleve 1971	Upland	<i>Pop trem</i>	Leaves	00.3	Deciduous		Reported in Hobbie et al. 2000
Van Cleve 1971	Upland	<i>Aln cris</i>	Leaves	39.7	Deciduous		Reported in Hobbie et al. 2000
Van Cleve 1971	Upland	<i>Bet pap</i>	Leaves	40.6	Deciduous		Reported in Hobbie et al. 2000
Vavrova et al. 2009	Lowland	<i>Pin syl</i>	Branches	7.8	Evergreen		Data estimated from manuscript
Vavrova et al. 2009	Lowland	<i>Pin syl</i>	Branches	7.8	Evergreen		Data estimated from manuscript
Vavrova et al. 2009	Lowland	<i>Pin syl</i>	Branches	10.0	Evergreen		Data estimated from manuscript
Vavrova et al. 2009	Lowland	<i>Pin syl</i>	Branches	12.2	Evergreen		Data estimated from manuscript
Vavrova et al. 2009	Lowland	<i>Pin syl</i>	Branches	14.4	Evergreen		Data estimated from manuscript
Vavrova et al. 2009	Lowland	<i>Pin syl</i>	Twigs	9.0	Evergreen		Data estimated from manuscript
Vavrova et al. 2009	Lowland	<i>Pin syl</i>	Twigs	11.0	Evergreen		Data estimated from manuscript
Vavrova et al. 2009	Lowland	<i>Pin syl</i>	Twigs	12.2	Evergreen		Data estimated from manuscript
Vavrova et al. 2009	Lowland	<i>Pin syl</i>	Twigs	15.6	Evergreen		Data estimated from manuscript
Vavrova et al. 2009	Lowland	<i>Pin syl</i>	Twigs	19.0	Evergreen		Data estimated from manuscript
Vavrova et al. 2009	Lowland	<i>Pin syl</i>	Twigs	20.0	Evergreen		Data estimated from manuscript
Wardle et al. 2003	Upland	<i>V. vitis-idaea</i>	Leaves	16.4	Evergreen		
Wardle et al. 2003	Upland	<i>Empetrum</i>	Leaves	24.6	Evergreen		
Wardle et al. 2003	Upland	<i>V. myrtillus</i>	Leaves	30.2	Deciduous		
Wardle et al. 2003	Upland	<i>Salix</i>	Leaves	33.1	Deciduous		
Wardle et al. 2003	Upland	<i>Betula</i>	Leaves	41.9	Deciduous		
Wardle et al. 2003	Upland	<i>Hyl</i>	Moss	11.9		Feather moss	
Wardle et al. 2003	Upland	<i>Ple sch</i>	Moss	23.2		Feather moss	
Wardle et al. 2003	Upland	<i>Picea</i>	Needles	17.6	Evergreen		
Wardle et al. 2003	Upland	<i>Pinus</i>	Needles	23.3	Evergreen		
Zhang et al. 2008	Upland	<i>Cas eyr</i>	Leaves	33.9	Deciduous		
Zhang et al. 2008	Upland	<i>Cas eyr</i>	Leaves	40.9	Deciduous		
Zhang et al. 2008	Upland	<i>Pin mas</i>	Needles	26.7	Evergreen		
Zhang et al. 2008	Upland	<i>Pin mas</i>	Needles	32.9	Evergreen		

**Note:** We limited our synthesis to studies that employed litter bags to examine mass loss rates over a 1-year period.

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